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THE FORECAST OF GEOMAGNETIC ACTIVITY UNDER THE ESTABLISHED CHARACTERISTICS OF SOLAR WIND MAGNETIC CLOUD

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Abstract. The influence analysis of magnetic cloud orientation and axis magnetic field on its geoeffective properties carried out. The magnetic cloud as force-free cylindrical flux rope is considered. The task of the short-term forecast of geomagnetic storm intensity expected at interaction of magnetic clouds with Earth's magnetosphere is considered. The forecast is basis on method of cloud parameters definition on few initial magnetic field components measurements on spacecraft. Well known connection geoeffective Bz component of Interplanetary Magnetic Field (IMF) vector with Dst-index geomagnetic activity take in attention.

1. Introduction

Source of the most geoeffective disturbance are coronal mass ejections (CMEs). At the motion to the Earth they often take closed formations with original plasma and magnetic field behavior in them. They are magnetic clouds [Bothmer et al., 1998]. Magnetic clouds are structures with magnetic field high amplitude, low temperature and low value β-plasma and monotonic rotation of magnetic field vector [Burlaga et al., 1981, Lepping et al., 1990]. Interest to The actual study of magnetic clouds is connected with their potential geoefficiency. They can contain magnetic field with large-amplitude vertical component Bz<0. That is the reason of significant growth geomagnetic activity during interaction of Earth's magnetosphere with cloud [Echer and Gonzalez, 2004].

In present time several models of magnetic clouds are developed [Romashets and Vandas, 2001; Vandas et al., 2002; Hidalgo et al., 2002]. The most widespread approach for cloud magnetic field modeling is force-free approach. It assumes that currents in cloud are parallel (or antiparallel) to force-lines of magnetic field, and perpendicular current component is absent. All developed approach will be coordinated with each other. Complication of model does not contribute to essential elaboration of key cloud parameters [Hidalgo et al., 2002]. Therefore in the given study force-free cylindrical model of clouds is used. The analytical expressions which describing behavior of magnetic field components inside such modeling cloud in coordinate solar-ecliptic system are received in [Barkhatov et al., 2009]. In this approach magnetic field cloud configuration is described of parameters: value of magnetic field on cloud axis, cloud radius, distance from line Sun-Earth to cloud axis (impact parameter), cloud axis orientation to ecliptic plane and magnetic field chirality. Cloud axis orientation to ecliptic plane is determined by polar and azimuthal angels. Magnetic field chirality indicates direction of its rotation in cloud.

Usually the analysis of magnetic clouds is carried out after they have completely passed through spacecraft, and, consequently, through Earth's magnetosphere [Wu and Lepping, 2002, Zhang et al., 2004]. However if you know magnetic field configuration of cloud approaching to the Earth, forecast intensity of expected geomagnetic storms is possible. In given study determination ranges of magnetic cloud parameters responsible for generation of various intensity magnetic storms are carried out. Development and testing technique of short-term forecast of geomagnetic storm intensity, expected at interaction of cloud with the Earth is carried out.

2. Base of force-free cylindrical model magnetic clouds

For analysis of magnetic cloud parameters and development of short-term forecast technique of expected geomagnetic storm intensity the base of modeling magnetic clouds has been created. The total quantity of modeling magnetic clouds is about 2 000 000. Each of modeling magnetic cloud corresponds to certain set of parameters. Ranges of modeling cloud parameters are established on the analysis of experimental data for real cases Solar plasma measurements from spacecrafts ACE and WIND from 1998-2001 [Lynch et al., 2003, Zhang et al., 2004]. In result, we selected following ranges of modeling cloud parameters: magnetic field on cloud axis -40 <Bo <41 nT (ΔBo=9 nT); radius 1 500 Re <Ro <4 992 Re (ΔRo=388 Re); azimuthal and polar angles 0^0 <β, ε <180^0 (Δβ, ε =20^0); impact parameter -1 250 <b < 1 252 (Δb=278Re); average velocity of cloud 350 <V <650 km·s^{-1} (ΔV=100 km·s-1), time interval passage spacecraft through cloud 10 <t <30 hours (Δt=5 hours). On the basis such change ranges of magnetic cloud parameters base of modeling clouds has been created.

3. Analysis of influence of magnetic cloud parameters on its geoeffectiveness

IMF Bz component has difficult distribution inside cloud. Its distribution depends on cloud configuration, i.e. on its parameters. It means that Dst-variation of geomagnetic disturbances, caused by interaction of cloud with Earth's magnetic field, depends on cloud parameters. On the basis of statistical relationship of amplitude Bz magnetic field components and Dst-index, it is possible to establish values of modeling cloud parameters responsible for generation of geomagnetic storm of the set intensity. Conformity of geomagnetic storm class on Dst-index to value IMF Bz components in Table 1 is resulted [Gonzalez et al., 1994]. For performance of analysis of cloud parameters influence on its geoeffectiveness from base events by duration of 25 hours, with radius 3 444 Re, average velocity 450 км·с$^{-1}$ and negative chirality have been selected. The selected magnetic clouds are large-scale and moving like to the Earth. Other could parameters changes according to ranges of base modeling cloud parameters.

Table1. Conformity of geomagnetic storm class (Dst-index interval) to Bz component value of IMF vector

Class storm	Dst (min), nT	Bz (three hours on end), nT
Weak	-30 – -50	-5
Moderate	-50 – -100	-10
Strong	-100 – -200	-15
Extreme	-200 – -350	-30

The establishment ranges of cloud parameters, corresponding to concrete geomagnetic storms class, under analysis magnetic field Bz component according to classification in Table 1 has been carried out. It was found, that the greatest number of cloud parameter combinations (43% from total numbers) can to cause strong magnetic storms that corresponds to result [Zhang et al., 2004]. Moderate storms (22%) and weak storms (24%) are caused by approximately equal number of magnetic cloud parameter combinations. Extreme storms can be caused only 11% of cloud parameter combinations. Further the detailed analysis of each modeling magnetic cloud parameters has been carried out. In result ranges of their values bringing the greatest contribution to geoeffective properties of cloud have been established. In Table 2 percentage ratio of modeling magnetic cloud configurations causing concrete geomagnetic storm class from the general numbers of considered clouds is submitted.

Table2. Value ranges of modeling magnetic cloud parameters and classes of magnetic storms which they can cause

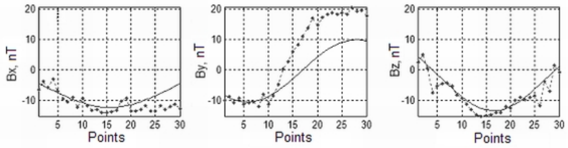
Ranges of change ε	***Weak storms***	***Moderate storms***	***Strong storms***	***Extreme storms***
±(-10÷30)	77%	50%	44%	-
±(30÷70)	22%	34%	39%	55%
±(70÷90)	1%	18%	17%	45%
Ranges of change β				
±(-10÷10)	13%	15%	12%	17%
±(10÷30)	21%	19%	16%	17%
±(30÷50)	23	21%	21%	19%
±(50÷70)	21%	23%	25%	22%
±(70÷90)	22%	22%	26%	25%
Ranges of change Bo				
-44 ÷ -36	2.8%	3%	20%	95.1%
-36 ÷ -2	4.6%	6.1%	37.4%	7.9%
-26 ÷ -18	19.4%	22.9%	28.5%	-
-18 ÷ -8	36.8 %	42%	-	-
-8 ÷ 1	-	-	-	-
1 ÷ 9	-	-	-	-
9 ÷19	17%	-	-	-
19 ÷ 26	12.8%	12.2%	-	-
26 ÷ 37	4.9%	11.1%	5%	-
37 ÷ 45	1.7%	2.7%	9.1%	-

4. Technique of short-term forecast of geomagnetic storms intensity caused by magnetic clouds

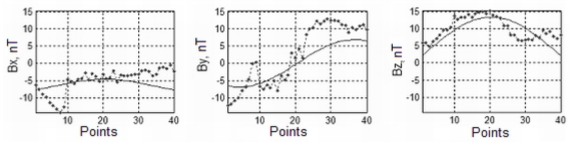
The technique of short-term forecast of geomagnetic storm intensity caused by magnetic clouds includes two basic stages. At the first stage establishment of cloud parameters on initial measurements magnetic field components and solar wind parameters on spacecraft is carried out. The description and testing this process is submitted in [Barkhatov et al., 2010]. On the received parameters restoration of full magnetic field structure in cloud is carried out. At the second stage the analysis of restored dynamics geoeffective Bz component in cloud is made. Further on the basis of Table 1 it is judged intensity of expected magnetic storm. The similar analysis for 27 CMEs, registered on spacecraft ACE from 1998 to 2001 and established at the literature as magnetic clouds [Lynch et al., 2003] has been carried out. For example we consider in detail three magnetic clouds. Data from ACE for IMF components and solar wind velocity with 30 minute averaging [http://www.srl.caltech.edu/ACE/, http: // cdaweb.gsfc.nasa.gov/cgi-bin/eval2.cgi] were used.

The magnetic cloud registered from ACE 16.04.1999

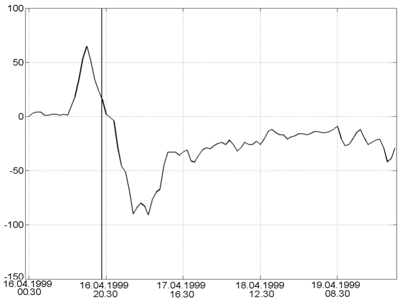
In Table 3 cloud parameters established at use of 28% data from full event are submitted. On them dynamics Bz magnetic field components in full cloud volume has been restored. Comparison of full registered magnetic field components and modeling, received at use 28% data, in Fig.1a is shown.



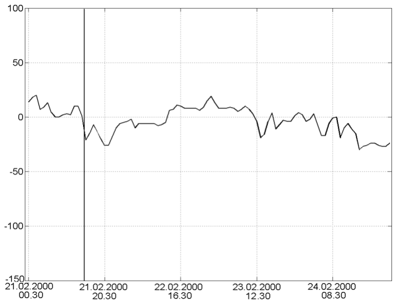
a)



a)



b)



b)

Fig. 1. Comparison of registered and modeling magnetic field components of clouds received at use of 28% data from full event. (a) Solid line – modeling magnetic field, points – real data. (b) Dst-index dynamics for 16–19.04.1999. The vertical line marks arrival time of cloud to the Earth

Fig. 2. The same, that in Fig.1, but for magnetic cloud 21.02.2000

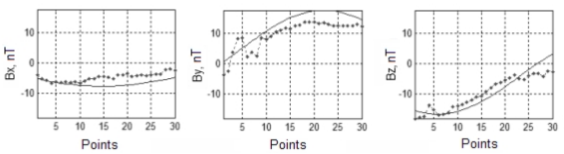
The analysis of restored dynamics Bz components (executed on basis of Table 1) has shown, that modeling cloud, contained in volume Bz <-10 nT within 6 hours on end. It means that such cloud should cause moderate storm. The real magnetic cloud has really caused moderate geomagnetic storm. Dynamics of Dst-index for analyzed period in Fig.1b is shown. The vertical line marks arrival time of cloud to the Earth.

The magnetic cloud registered from ACE 21.02.2000

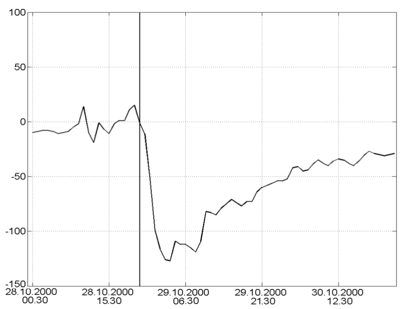
In Table 3 parameters of given cloud established at use 48% data from full event are submitted. Comparison of full registered magnetic field components and modeling, received at use of 48% data, in Fig.2a is shown. The given modeling cloud did not contain in volume Bz<0 nT. Such cloud would not cause magnetic storm. The real magnetic cloud has not caused geomagnetic storm (Fig.2.b).

The magnetic cloud registered from ACE 28.10.2000.

In Table 3 cloud parameters, established at use 39% data from full event, are submitted. Comparison of full registered magnetic field components and modeling, received at use 39% data, in Fig.3a is shown. The analysis of dynamics Bz components has shown that a modeling cloud contained in volume Bz <-15 nT within 8 hours on end. Such cloud should cause strong storm. The real magnetic cloud has really caused strong geomagnetic storm (Fig.3b).



a)



b)

Fig. 3. The same, that in Fig.1, but for magnetic cloud 28.10.2000

Table3. The parameters of analyzed clouds determined on initial measurements magnetic of field components

Data registration magnetic cloud	H	Bo, nT	Ro, Re	β, deg	ε, deg	b, Re	V, $km \cdot s^{-1}$	L, h	Percent data on which parameters are established
16.04.1999	-1	-22	1888	60	80	974	450	15	28
21.02.2000	+1	23	1500	180	140	1252	350	20	48
28.10.2000	-1	-22	3052	80	-40	974	450	15	39

5. Conclusions

The analysis of influence of large-scale magnetic cloud parameters on geoefficiency has allowed establishing the ranges of their values responsible for development of various intensity geomagnetic storms. It is received, that extreme storms are generated clouds with great values of polar angel and strong negative magnetic field on cloud axis. For development of strong geomagnetic storms enough high values of magnetic field on cloud axes. Weak geomagnetic storms are caused mainly by clouds with small polar angel and almost all value ranges of axis field. On real events the technique of short-term forecasting of geomagnetic storms intensity expected at interaction of clouds with Earth's magnetosphere is developed and checked up. It is received high (~80%) conformity of intensity classes of the geomagnetic storms, caused real by magnetic clouds and expected from modeling events. Divergences in classes of real and expected geomagnetic storms it is observed for magnetic clouds at which the cloud sheath or combination of sheath and leading field is geoeffective. However such events make only ~20%, therefore the suggested technique can be used for short-term forecast of geomagnetic storms intensity caused by clouds.

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